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Voltage stability analysis of radial distribution networks

M. Chakravorty, D. Das*

Department of Electrical Engineering, Indian Institute of Technology, Kharagpur 721302, West Bengal, India

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Abstract

The paper presents voltage stability analysis of radial distribution networks. A new voltage stability index is proposed for identifying the node, which is most sensitive to voltage collapse. Composite load modelling is considered for the purpose of voltage stability analysis. It is also shown that the load flow solution of radial distribution networks is unique. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Radial distribution networks; Voltage stability analysis

1. Introduction

A power system is an interconnected system composed of generating stations, which convert fuel energy into electricity, substations that distribute power to loads (consumers), and transmission lines that tie the generating stations and distribution substations together. According to voltage levels, an electric power system can be viewed as consisting of a generating system, a transmission system and a distribution system.

The transmission system is distinctly different, in both its operation and characteristics, from the distribution system. Whereas the latter draws power from a single source and transmits it to individual loads, the transmission system not only handles the largest blocks of power but also the system. The main difference between the transmission system and the distribution system shows up in the network structure. The former tends to be a loop structure and the latter generally, a radial structure.

The modern power distribution network is constantly being faced with an ever-growing load demand. Distribution networks experience distinct change from a low to high load level everyday. In certain industrial areas, it has been observed that under certain critical loading conditions, the distribution system experience voltage collapse. Brownell and Clarke [1] have reported the actual recordings of this phenomenon in which system voltage collapses periodically and urgent reactive compensation needs to be supplied to avoid repeated voltage collapse.

Literature survey shows that a lot of work has been done on the voltage stability analysis of transmission systems [2], but hardly any work has been done on the voltage stability analysis of radial distribution networks. Jasmon and Lee [3] and Gubina and Strmchnik [4] have studied the voltage stability analysis of radial networks. They have represented the whole network by a single line equivalent. The single line equivalent derived by these authors [3,4] is valid only at the operating point at which it is derived. It can be used for small load changes around this point. However, since the power flow equations are highly nonlinear, even in a simple radial system, the equivalent would be inadequate for assessing the voltage stability limit. Also their techniques [3,4] do not allow for the changing of the loading pattern of the various nodes which would greatly affect the collapse point.

In this paper, a new voltage stability index for all the nodes is proposed for radial distribution networks. It is shown that the node at which the value of voltage stability index is minimum, is more sensitive to voltage collapse. Composite load modelling is considered for voltage stability analysis. It is also shown that the load flow solution with feasible voltage magnitude for radial distribution networks is unique.

2. Methodology

In Ref. [5], a simple load flow technique for solving radial distribution networks has been proposed. For the purpose of

* Corresponding author. Tel.: +91-3222-83042; fax: +91-3222-55303.
E-mail address: ddas@ee.iitkgp.ernet.in (D. Das).

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Nomenclature

NB	total number of nodes
*LN*1	total number of branches
TPL	total real power load
TQL	total reactive power load
jj	branch number
IS(*jj*)	sending end node
IR(*jj*)	receiving end node
r(*jj*)	resistance of branch *jj*
x(*jj*)	reactance of branch *jj*

deriving the voltage stability index of radial distribution networks, this load flow technique [5] will be explained in brief:

Fig. 1 shows a 15-node sample radial distribution network and Fig. 2 shows the electrical equivalent of Fig. 1.

From Fig. 2, the following equations can be written:

$$I(jj) = \frac{V(m1) - V(m2)}{r(jj) + jx(jj)}, \tag{1}$$

$$P(m2) - jQ(m2) = V^*(m2)I(jj) \tag{2}$$

where

jj = branch number,
$m1$ = branch end node = $IS(jj)$,
$m2$ = receiving end node = $IR(jj)$,
$I(jj)$ = current of branch jj,
$V(m1)$ = voltage of node $m1$,
$V(m2)$ = voltage of node $m2$,
$P(m2)$ = total real power load fed through node $m2$,
$Q(m2)$ = total reactive power load fed through node $m2$.

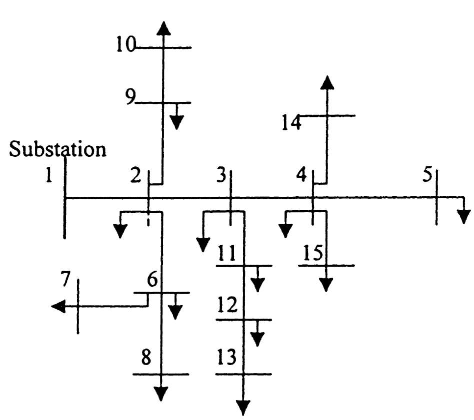

Fig. 1. Single line diagram of a radial distribution feeder.

From Eqs. (1) and (2), we get

$$|V(m2)|^4 - \{|V(m1)|^2 - 2P(m2)r(jj) - 2Q(m2)x(jj)\}|V(m2)|^2 + \{P^2(m2) + Q^2(m2)\}\{r^2(jj) + x^2(jj)\} = 0. \tag{3}$$

Let,

$$b(jj) = |V(m1)|^2 - 2P(m2)r(jj) - 2Q(m2)x(jj)\}, \tag{4}$$

$$c(jj) = \{P^2(m2) + Q^2(m2)\}\{r^2(jj) + x^2(jj)\}. \tag{5}$$

From Eqs. (3)–(5) we get,

$$|V(m2)|^4 - b(jj)|V(m2)|^2 + c(jj) = 0. \tag{6}$$

From Eq. (6), it is seen that the receiving end voltage $|V(m2)|$ has four solutions and these solutions are:

1. $0.707[b(jj) - \{b^2(jj) - 4c(jj)\}^{1/2}]^{1/2}$,
2. $-0.707[b(jj) - \{b^2(jj) - 4c(jj)\}^{1/2}]^{1/2}$,
3. $-0.707[b(jj) + \{b^2(jj) - 4c(jj)\}^{1/2}]^{1/2}$,
4. $0.707[b(jj) + \{b^2(jj) - 4c(jj)\}^{1/2}]^{1/2}$.

Now, for realistic data, when P, Q, r, x and V are expressed in per unit, $b(jj)$ is always positive because the term $2\{P(m2)r(jj) + Q(m2)x(jj)\}$ is very small as compared to $|V(m1)|^2$ and also the term $4c(jj)$ is very small as compared to $b^2(jj)$. Therefore $\{b^2(jj) - 4c(jj)\}^{1/2}$ is nearly equal to $b(jj)$ and hence the first two solutions of $|V(m2)|$ are nearly equal to zero and not feasible. The third solution is negative and so not feasible The fourth solution of $|V(m2)|$ is positive and feasible. Therefore, the solution of Eq. (6) is *unique*. That is

$$|V(m2)| = 0.707[b(jj) + \{b^2(jj) - 4.0c(jj)\}^{1/2}]^{1/2}. \tag{7}$$

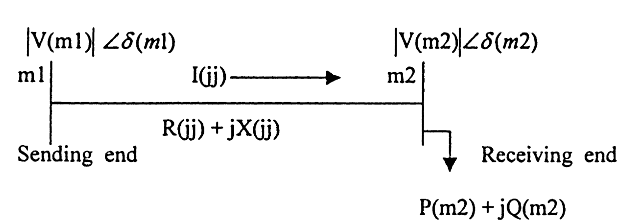

Fig. 2. Electrical equivalent of Fig. 1.

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